In an ancient southern Australian rift valley, a carnivorous allosaur strides along a stream bed as a labyrinthodont amphibian dips beneath the water's surface and hypsilophodonts retreat to vegetation along the bank.

Paintings by Peter Schouten

The Dinosaurs of Winter

Neither cold nor dark of night stopped the hypsilophodonts

by Patricia Vickers-Rich and Thomas H. Rich

The next to the last day of a long (and at times tiresome) 1987 field season got under way late when our team of excavators and rock bashers finally gathered at the site at about 9:00 A.M. No one was in much of a hurry, for after nearly two months of the same grueling work, you can't push yourself too hard too early, or you won't last past noon. Digging dinosaurs can be quite easy and also a great deal of fun if the bones happen to be abundant, well preserved, and exposed in soft sediments, such as clays or sands. Here at Dinosaur Cove, and at all the other localities producing dinosaurs along the southern coast of Victoria, Australia, fossils are not so easily won. Although the bones are exquisitely preserved, they are embedded in hard sandstones, siltstones, and claystones that can only be excavated using proper mining tools—jackhammers, big drills, and explosives. And for all our blasting and drilling, this field season had been a disappointment. Not many fossil specimens had turned up, and we were about to call it quits at this locality.

This season, the crew—many of them dedicated amateurs and volunteers—had dug two parallel tunnels into a cliff following an ancient stream channel in which bones had accumulated more than 100 million years ago. Subsequently, we decided to link the two tunnels together by a cross tunnel, a most fortuitous decision, for only in this third tunnel was much of consequence ultimately found. After blasting and drilling away the overlying rock, the crew gently took up the fossil-bearing layer from the floor of the "dinosaur mine," handling even the sharpest and heaviest rocks like newborns.

On this penultimate day, a crew member examining a recently split rock for a second time spotted a most unusual specimen in the gray light of the tunnel. Not surprisingly, it had been overlooked at first; the tunnels were not only dark but also muddy and cramped, and the specimen itself was dark brown against the encasing dark gray rock. The find proved to be the top of a fossilized skull of a dinosaur that could have been no larger than a chicken. A fresh break suggested that there was more to the specimen than we had found. A frantic effort soon led to the recovery of the missing counterpart, a fragment of the skull roof that during excavation had been peeled off like an orange rind. The imprint of the top of the brain—a large brain for a dinosaur—was clearly visible. What was more, the optic lobes, those parts of the brain dedicated to sight, were huge. Later we learned that in no other dinosaur of its kind—and in few dinosaurs of any kind—were the optic lobes prominent enough to have made a distinct impression on the skull roof.

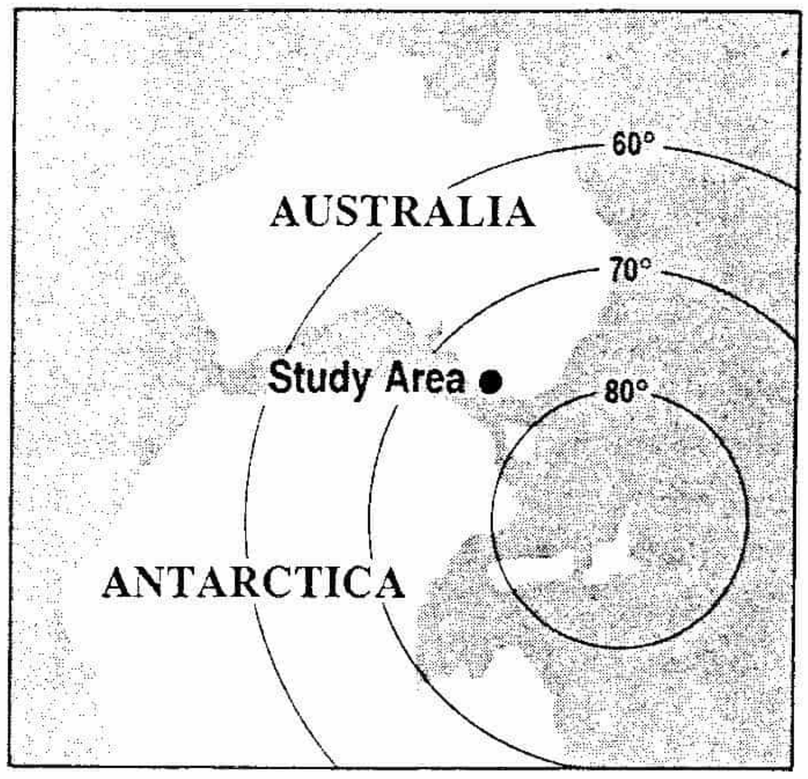
That day we were in luck three times: We found the specimen in the third tunnel after the first two had yielded almost nothing. We recovered all of what had been preserved of the skull. And as we dug out the tunnel, a drill hole with a diameter about the same size as the skull had missed the fossil by a mere four inches.

The next day, we were lucky a fourth time, for less than three feet from the skull fragments, we found the remnant of a leg and a significant part of a backbone and pelvis. Our first impression was that these bones were just the right size for our dinosaur, and subsequent lab work and fossil comparisons have largely borne this out. This brainy, large-eyed dinosaur, which lived about 106 million years ago, turned out to be a new species of hypsilophodont, a small, swift, bipedal plant- and insect-eater. We eventually dubbed it *Leaellynasaura amicagraphica.*

One would imagine that finding such a specimen after two months of nearly fruitless effort would release a joyous pandemonium among the crew. However, it was quite unlike that. After searching so long and so hard, we were emotionally numb, and only gradually did we realize that we had uncovered an important clue to life in this area about 106 million years ago.

Australia's fossil record of dinosaurs, and terrestrial vertebrate life in general, from about 220 to 65 million years ago, is almost nonexistent. The first dinosaur bone from the Victorian coast was discovered by a geologist about 1900. Eighty years passed before another dinosaur bone surfaced. The emergent mammalian fauna of Australia of this time is represented by just two jaw fragments. Numerous trackways and the rarer fossil bones support the notion that dinosaurs were abundant and dominant in Australia, but the evidence available until now has been exceedingly sparse, affording us merely a glimpse of life at that time. Ever since the 1960s, when we were university students working at the American Museum of Natural History in New York, we had wanted to find some pieces that would fill in this

Joe LeMonnier



One hundred and six million years ago, Dinosaur Cove lay close to the South Pole. The land masses of what are now Australia and Antarctica were not yet separated by the Southern Ocean, and shallow inland seas covered portions of Australia.

part of the Australian puzzle, to broaden the glimpse to a gaze.

Dinosaur Cove is situated in one of the prime places in southern Australia for recovering fossil bones. Along the coast, rocky outcrops in the Strzelecki and Otway ranges, southeast and southwest of Melbourne, have escaped deep weathering and the fossils they bear have not been subjected to the chemical erosion typical on much of the continent. The entire area of these coastal, dinosaur-bearing rocks in Victoria is a single square mile. The pounding action of the waves tears away at these rocks, exposing, but not dissolving, dinosaur bones. Only about 300 feet inland, the same kinds of rocks are so deeply weathered as to make hunting for fossil bones a futile exercise.

Today, from Dinosaur Cove the view to the north is of the low Otway range and to the south, the open expanse of the Southern Ocean. More than 1,800 miles away lies Antarctica. When the dinosaurs were living here, however, the scene would have been quite different. The Southern Ocean did not exist. Rather, the area was the floor of a rift valley. Australia and Antarctica, long fused as part of the great southern continent of Gondwana, were just beginning to separate from each other. At that time, one could have walked to Antarctica from the spot that is now Dinosaur Cove. The floor of the rift valley was almost flat, with perhaps a distant view of the Australian valley wall on the far northern horizon.

One hundred and six million years ago, in the early Cretaceous, southeastern Australia lay well within the Antarctic Circle of the day, perhaps as far as 80° south latitude. From the fossils of plants and invertebrates collected at Dinosaur Cove and other contemporaneous Victorian sites, we know that the climate then, while not as frigid as the polar regions today, was far from equable. Fossilized trees contain prominent rings, reflecting marked seasonal shifts. Oxygen isotope ratios determined for the rocks at Dinosaur Cove suggest that the mean annual temperature in southeastern Australia in the early Cretaceous was not higher than 41° F, and perhaps as low as 21° F. Summer tem-

The well-preserved fossil skull of a chicken-sized, herbivorous dinosaur, Leaellynasaura amicagraphica, *left, retains the impression of a large brain (at bottom) with huge optic lobes. Evidence of ancient bird life in southern Australia comes from fossil feathers. Below: One of the feathers found in fossil beds at Koonwarra is less than an inch long.*

Photographs by Steven Morton and Frank Coffa

peratures might have been quite warm, but during the long winter nights the air must have been well below freezing. Studies of ancient river valley sediments in the area point to periodic flooding, perhaps the result of runoff of seasonal meltwater from snowfields at higher elevations. (A decade ago, polar dinosaurs were unrecognized in either hemisphere, except for some footprints from Spitsbergen. Since then, a massive concentration of fossil bones, primarily those of duck-billed dinosaurs, has come to light on the Colville River on the North Slope of Alaska. Additional discoveries of isolated specimens in both hemispheres—including Alaska, Canada, Siberia, New Zealand, and the Antarctic Peninsula—hold promise of providing a much broader picture of high-latitude dinosaurs in years to come.)

Nevertheless, Dinosaur Cove and its environs supported abundant life in the Mesozoic. The new hypsilophodont fossils were among the most intriguing of a variety of plant and animal remains of similar age uncovered in Victoria in the late 1970s and the 1980s. We now had a better opportunity to reconstruct the ancient polar environment and to try to determine how the creatures of Dinosaur Cove, particularly the dinosaurs, could have coped with long, warm summer days and equally long, cold winter nights. To begin with, we placed the hypsilophodonts in context, piecing together a picture of their polar world.

The work thus far on the Victorian dinosaurs and their associated flora and fauna has revealed more than 150 different species, from spiders to pterosaurs, ferns to conifers. The landscape was relatively green and lush, given its geographical location. Large, nonflowering plants, including monkey puzzle trees, ginkgoes, and podocarps, dominated the flora. Ferns abounded, with some types sharing the undergrowth with bryophytes and other low-growing vegetation, and with other kinds proliferating on the forest fringes. *Lycopodium,* a primitive vascular plant, and sphagnum mosses grew in more open moorlands, while quillworts, hepatics, and algae dominated the aquatic environments. A few rare species represented the new tribe of flowering plants. By the time the dinosaurs became extinct about 65 million years ago, flowering plants had come to rule the terrestrial flora, but in southern Victoria more than 100 million years ago, they would have hardly been noticed in an otherwise uniformly green plant community.

Modern relatives of many of these plants are found in the mountains of southeastern Australia and in Tasmania's high country, where they are often covered with snow during the winter. While they also inhabit some warmer climes, their habitat range suggests that their Mesozoic ancestors could have coped with winter conditions at what is now Dinosaur Cove.

More than eighty species of invertebrates are also associated with the dinosaur faunas. Most come from one remarkable locality, Koonwarra, in the Strzelecki range to the southeast of Melbourne. Spiders, freshwater bryozoans, shellfish, and what are possibly earthworms, along with a diversity of crustaceans, have been

A variety of hypsilophodonts, including agile, large-eyed Leaellynasaura *(foreground) and the larger* Atlascopcosaurus *(top), foraged in the relatively lush, cool-temperate rain forests of early Cretaceous age in Australia.*

found in the ancient lake sediments preserved at Koonwarra. Of the twelve orders of insects present, the bugs, beetles, and flies are the most varied, and many immature individuals are preserved.

Antarctic Australia was also home to a variety of fish, including lungfish, which today have a very restricted range in the swamps and marshes of tropical Africa and South America, as well as the rivers of northeastern Australia. Several other bony fish groups, some rather primitive when compared with most living fish, inhabited these ancient rivers and streams.

Birds have left only feathers to signal their presence, but bones of amphibians, turtles, pterosaurs, and lizardlike reptiles, as well as teeth of the long-necked, Loch Ness "monster"-like plesiosaurs, have been found. Although most plesiosaurs were ocean dwellers, the Australian ones inhabited fresh water. Just as some seals and dolphins, for example the Ganges River dolphin, today sometimes invade rivers and lakes, so, too, must have some Cretaceous plesiosaurs. They were a long way from the nearest ocean.

An intriguing aspect of the fossil vertebrate fauna is that it contained several forms that had long since become extinct elsewhere in the world. These included the bipedal carnivore *Allosaurus* and the youngest surviving labyrinthodont amphibian, a large, semiterrestrial, carnivorous form. These vertebrates survived tens of millions of years beyond their time elsewhere. They were "living fossils" even in the early Cretaceous. Perhaps because of its polar location, Australia served as a refuge for many different kinds of animals and plants.

More than half of the approximately 200 dinosaur fossils recovered are those of juveniles. Dinosaurs were not just visiting the area occasionally; they were most likely using it as a nursery, taking advantage of the high productivity that such a polar area sustained during the summer months, when the sun shone twenty-four hours a day.

Large rivers, which eventually became choked with sediments, flowed across the early Cretaceous Victorian valley floor. Smaller, more gently flowing streams that fed into those rivers were ultimately filled with a mixture of clays and finer sands. It is in the latter that the rare fossils of vertebrates, most from diminutive creatures, are most frequently found. Nevertheless, larger dinosaurs were present, a fact established by the finds of a few isolated bones. In every case, these were the smallest bones on which it is possible to base the identification of the larger animals, and frequently, these specimens appear to have been from juveniles. Even the carnivorous allosaurs were small in stature compared with specimens in North America, for example. This trend holds for the hypsilophodont dinosaurs, too; the tallest reached only the size of a human of medium height.

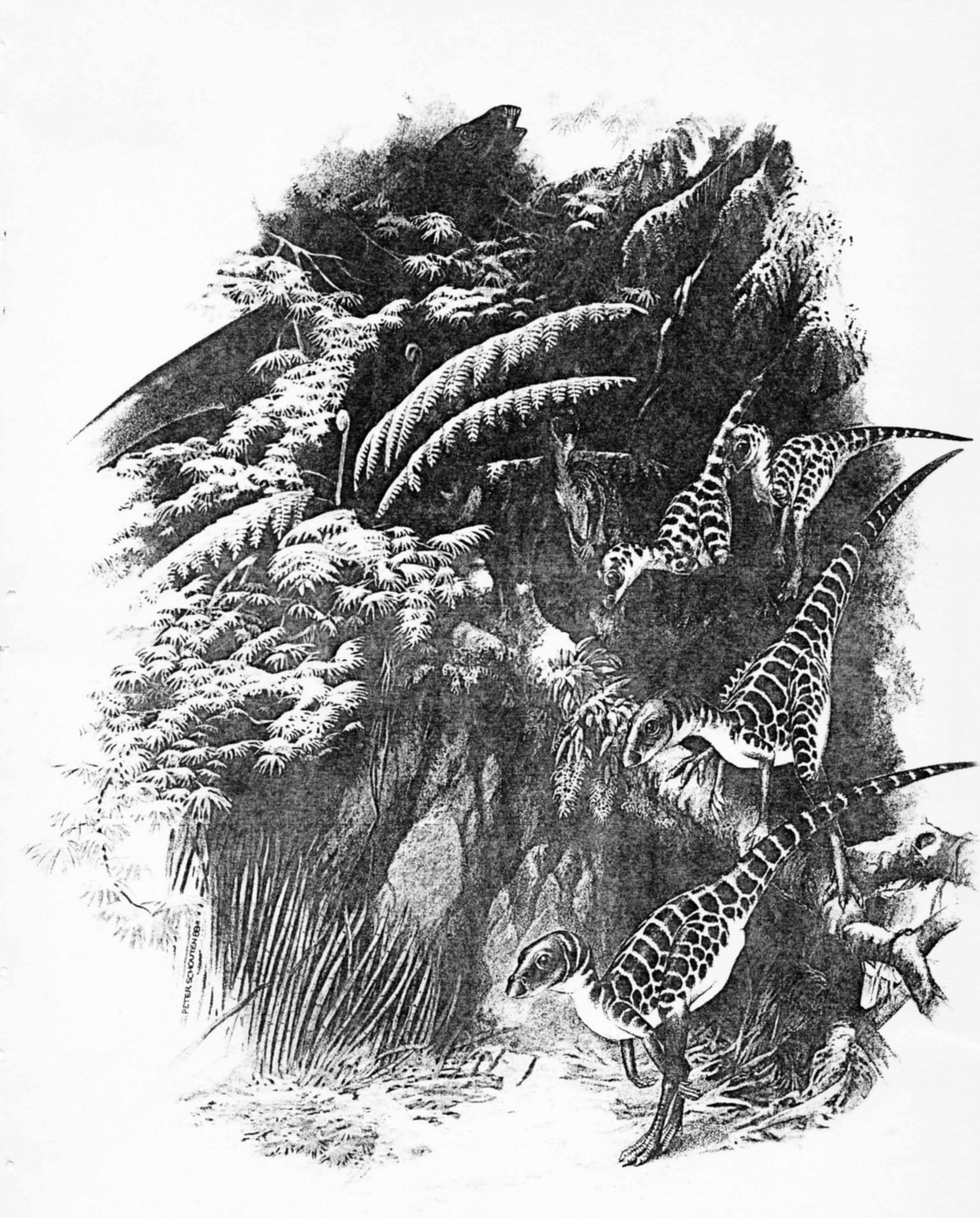
The herbivorous dinosaurs were all hypsilophodonts, like *Leaellynasaura amicagraphica*. Elsewhere in the world, hypsilophodonts are generally a rare element in museum fossil collections, and typically only one or at best a few different kinds are known in one area and of one age. In southeastern Australia, the quantity of material, although small, indicates that up to five different species of this single family may have been living here, all at about the same time. Members of this family seem to have thrived at this polar latitude. Did they survive the winters by migrating or perhaps by hibernating? Or did they remain active even during the most stressful times of the year?

A look at a paleogeographic map of Australia for this period indicates that migration to lower latitudes would not be a simple matter of going directly north. Because of the shallow sea that covered much of northeastern Australia, to reach the Antarctic Circle (and thus some daylight every day of the year) on dry land would have required migrating to the northwest about 600 miles. Although modern caribou do migrate a comparable distance in the Northern Hemisphere, no smaller terrestrial mammals the size of *Leaellynasaura* do. And in any case, at the Antarctic Circle on the shortest days of the year, the sun will shine only briefly on the southern horizon at noon.

Although reptiles do live north of the Arctic Circle today, they accomplish this by burrowing into the mud and hibernating. Even in temperate climates, modern reptiles cease to be active when the daily average temperature approaches freezing. The clue to the hypsilophodonts' winter habits, and the answer to the hibernation question, may lie in these dinosaurs' large brains.

Why would *L. amicagraphica* have developed particularly prominent optic lobes on its brain, while members of its family from other continents did not? Of all other dinosaurs, only the "brainiest" ones, the small carnivores such as the North American *Troodon,* could match it. Sharper sight seems to be the most plausible answer. The only prominent difference between this dinosaur and the other members of its family is where it lived: close to the South Pole of the day. Presumably, the enhanced eyesight would not have been needed during the polar summer, when plenty of light was available. If this unusual ability was required because of the low light levels encountered during the winter, it would imply that *Leaellynasaura* was active even during winter, when the temperatures were probably below freezing for prolonged periods. This idea, in turn, lends support to, but by no means proves, the hypothesis that some dinosaurs were warmblooded.

Intensive prospecting and excavation since the late 1970s have produced remarkable assemblages of flora and fauna that are altering our views of world climates 100 to 120 million years ago. Even though temperatures were, in general, globally higher, polar areas most certainly experienced low temperatures and seasonal fluctuations that would have been quite stressful to living things. Some dinosaurs, however, were able to cope with these conditions. Understanding just how they coped and under what conditions they lived will undoubtedly contribute to understanding why dinosaurs, as a group, disappeared at the end of the Cretaceous. Dinosaurs and other creatures that survived in south polar climes 106 million years ago may also give us a better estimate of when, and how rapidly, the changes leading to our modern glacial climate took place. □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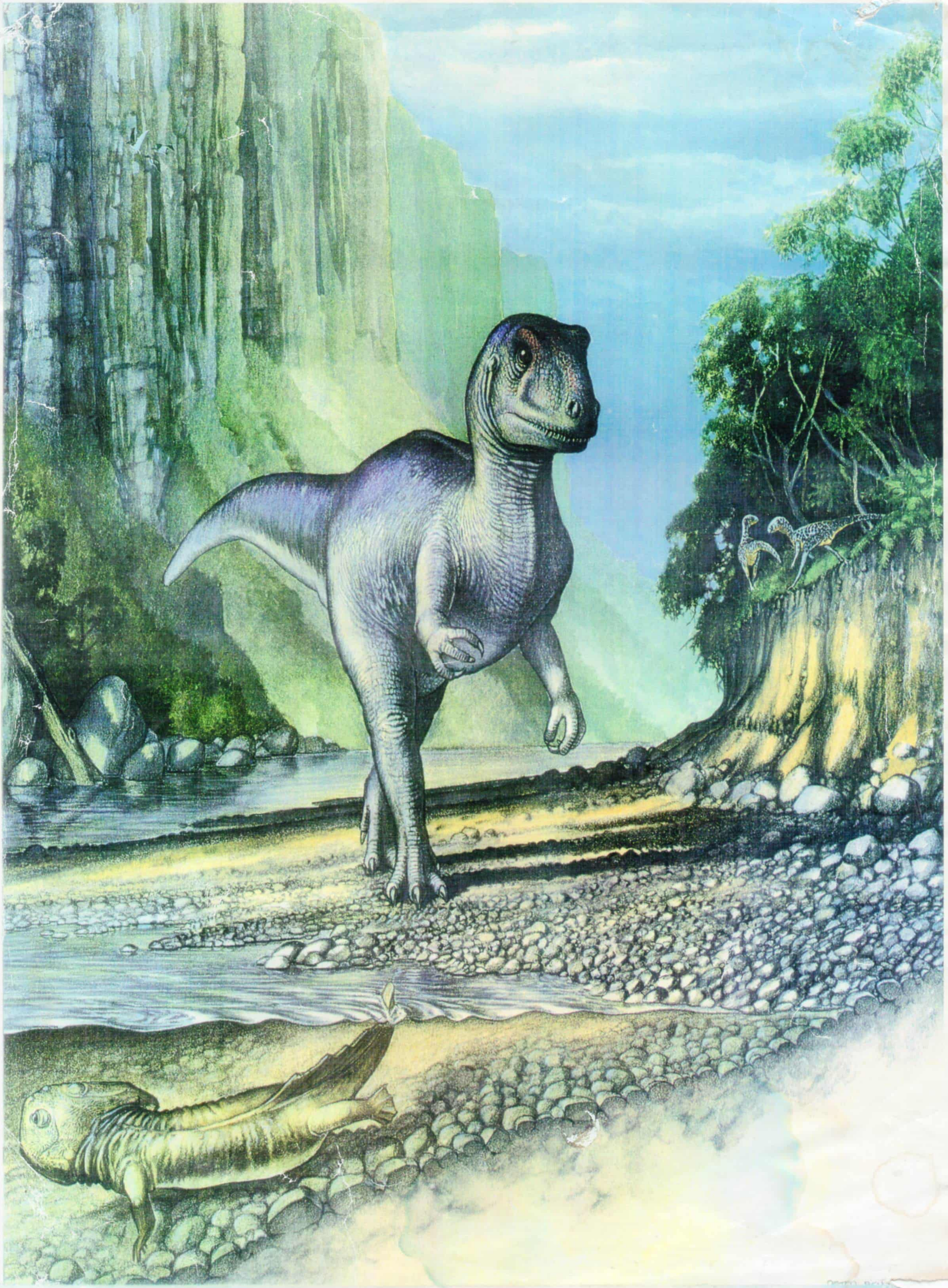

Transplanted Americans, **Patricia Vickers-Rich** and **Thomas H. Rich** (page 32) have been excavating fossils and teaching in Australia since the mid-1970s. Both studied paleontology at the University of California at Berkeley and earned doctorates in geology at Columbia University in New York. Interested in natural history "since at least four years of age," Patricia is now a reader in the earth sciences and biology departments at Monash University in Clayton, Victoria, while Tom is a curator of vertebrate paleontology at the Museum of Victoria in Melbourne. Sponsored by a variety of organizations, including the Australian government and the National Geographic Society, the Riches' fieldwork in southern Australia has been carried out with the help of hundreds of students and volunteers, many from Earthwatch, who have, over the years, dug, blasted, and hauled tons of rock at Dinosaur Cove. The Riches have also brought an awareness of Australia's fossil history to the general public through television documentaries and educational programs. Authors and editors of many books, Pat and Tom Rich collaborated with Mildred Adams Fenton on a revision of *The Fossil Book* (New York: Doubleday and Company, 1989), an illustrated guide to prehistoric life. Australia's fossil record is the subject of *Kadimakara: Extinct Vertebrates of Australia,* edited by P. V. Rich and G. F. van Tets, illustrated by F. Knight (Princeton: Princeton University Press, 1990), and *Vertebrate Zoogeography and Evolution in Australia,* edited by M. Archer and G. Clayton (Carlisle, Australia: Hesperian Press, 1984).